APPENDIX B

UV DISINFECTION SYSTEM DESIGN EXAMPLE

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Scheible[30] has presented a simplified design example to demonstrate how the model expression **[5]** can be used to design a new system.

STEP 1: WASTEWATER DATA COLLECTION.

a. The treatment plant is a conventional activated sludge facility with the following design conditions:

Q_{avg} = 1.9 MGD (5000 l/min)
Q_{peak} = 3.8 MGD (10000 l/min)
UV Transmittance, T_r, measured of 67%
Total Suspended Solids (TSS) = 20 mg/l
Initial Fecal Coliform N_0 = 200,000/100 ml
Disinfection Goal **N**, 200/100 ml from effluent permit.

b. Calculate absorbance units per centimeter (**A**/cm)

$$\% \text{ Transmittance}, T_r, = 100 \times 10^{-(A/cm)}$$

$$67 = 100 \times 10^{-(A/cm)}$$

$$A/cm = 0.174$$

<u>Calculate UV Coefficient of Absorption, α</u>

$$\alpha = A \times 2.3 = 0.174 \times 2.3 = 0.4 \text{ cm}^{-1}$$

STEP 2: MODEL COEFFICIENT AND PARAMETERS.

From the literature **c** = 0.26, **m** = 1.96, **a** = 1.45×10^{-5} and **b** = 1.3

Therefore, for the example:

$$N_p = c(TSS)^m$$
$$N_p = 0.26(TSS)^{1.96} \quad [6]$$

and

$$K = a\,(I_{avg})^b$$
$$K = 1.45 \times 10^{-5}(I_{avg})^{1.3} \quad [7]$$

STEP 3: ESTABLISH REACTOR PARAMETERS AND EQUIPMENT CONDITIONS.

For illustrative purposes, the configuration chosen is a uniform array, with a centerline spacing, **S**, of 5.5 cm. The lamps will be G64T5 (Table 4-2), have an arc length, **Z**, of 1 x 47 cm, and a rated (nominal) UV output of 26.7 W at 253.7nm. Each lamp is sheathed in a quartz sleeve with diameter, d_q, of 2.3 cm. The dimensional layout of the array is depicted in Figure 4-15a, with the volume associated with each lamp/quartz included. In a uniform array, lamp spacing, $S=S_v=S_h$.

The average nominal intensity is presented on Figure 4-16 as a function of the UV coefficient of absorption. The lamps will be configured axially parallel to one another and the flow path perpendicular to the lamps. The values of the energy loss factors, F_p and F_t are set at 0.8 and 0.7, respectively as discussed in paragraph 3.3.1 step 3f. The maximum allowable headloss through the battery of lamps is set at 40 cm (16 in) and is exclusive of entrance and exit losses for the reactor.

STEP 4: DETERMINE REACTOR UV DENSITY

Compute Liquid Volume (Void Volume)

The liquid volume associated with each lamp/quartz is computed from:

$$V_v \text{ per lamp} = (S^2 Z) - [\pi Z\, d_q^2/4] \qquad [10]$$
$$V_v \text{ per lamp} = [(5.5)^2(147)] - [\pi(147)(2.3^2/4)]$$
$$V_v \text{ per lamp} = 3840 \text{ cm}^3 \text{ (3.84 lit)}$$

Compute UV Density, D

$$D = \text{Total UV output/liq vol} \qquad [9]$$
$$D = \text{arc length x UV output/liq vol}$$
$$D = (26.7 \text{ w}/3.84 \text{ liter})$$
$$D = 7 \text{ w/l}$$

STEP 5: UV INTENSITY.

Determine Nominal Intensity

Enter Figure 4-16 (uniform array) with known values of D = 7 w/l and coefficient of absorption, α, = 0.40 cm^{-1} and read nominal I_{avg} of 17,500 $\mu w/cm^2$.

Adjust Intensity

$$I_{avg} = Nom\ I_{avg} \times F_p \times F_t \qquad [8]$$
$$I_{avg} = 17{,}500 \times 0.8 \times 0.7$$
$$I_{avg} = 9{,}800\ \mu w/cm^2 \quad \text{(adjusted)}$$

STEP 6: INACTIVATION RATE

$$K = a\ (I_{avg})^b \qquad [7]$$
$$K = 1.45 \times 10^{-5}\ (9{,}800)^{1.3}$$
$$K = 2.24/sec$$

STEPS 7 and 8: SET HYDRAULIC LOADING RATE AND UV LOADING/PERFORMANCE

UV Loading Rate = Q/W_n where Q = peak flow in lpm and W_n = nominal wattage. Once the loading is set, the nominal exposure time, t_n, is set using:

$$t_n = (V_v/W_n)/(Q/W_n) \qquad [12]$$

For the example,

$$V_v/W_n = 1.144/W_n$$

and

$$t_n = (0.144/W_n)/(Q/W_n)$$

Calculate Dispersion in the Reactor

Set, dimensionless dispersion number, d_n, defined as $d_n = E/ux = 0.01$. Set $E = 15\ cm^2/sec$ which is similar to dispersion coefficients determined by test results. Thus **ux** must be greater than 15/0.01 cm^2/sec, and $u = 1500/x$.

Velocity **u** = UV exposure length/UV exposure time =

$$u = x/t_n$$

Expression for Effective Length of Reactor:

Substituting: $1500/x = x/t_n$

and $x = (1500\ t_n)^{1/2}$ [15]

Table B-1 shows a summary of the calculations used to determine log (N'/N_0) for the configuration spacing, S = 5.5 cm. The log (N'/N_0) values are plotted in Figure B-1 as a function of the Q/W_n ratios. Note that the UV performance is based on the non-particulate effluent fecal coliform density. The particulate fecal coliform , density, N_p, would be additive.

Table B-1 Calculation of performance based on loading (uniform array, S = 5.5 cm)

Loading Q/W_n lpm/W_n	Nominal[a] time, t_n (Sec)	Length[b] x (cm)	Velocity[c] u (cm/s)	log N'/N_0[d] at K of $2.24 s^{-1}$
0.5	17.2	160	9.3	-12.90
1.0	8.6	113	13.1	- 7.22
1.5	5.8	93	16.0	- 5.06
2.0	4.3	80	18.6	- 3.84
3.0	2.9	66	22.8	- 2.62
4.0	2.2	57	25.9	- 2.06
6.0	1.4	46	33.0	- 1.03

a $t_n = [0.144/W_n)/(Q/W_n)] \times 60$ sec/min

b $x = (1500\ t_n)^{1/2}$

c $u = x/t_n$

d $N'/N_0 = \exp\ [(ux/2E)\{1-(1+4KE/u^2)^{1/2}\}]$ for $E = 15\ cm^2/sec$ and $K = 2.24/sec$

STEP 9: ESTABLISH PERFORMANCE GOALS

<u>Calculate Particulate Coliform Density</u> (N_p)

For TSS = 20 mg/l (Step 1'), c = 0.26, and m = 1.96:

$$N_p = c(TSS)^m \quad [6]$$
$$N_p = 0.26\ (20)^{1.96}$$
$$N_p = 92/100\ ml$$

<u>Calculate N'</u>:

$$N' = (N - N_p) \quad [16]$$

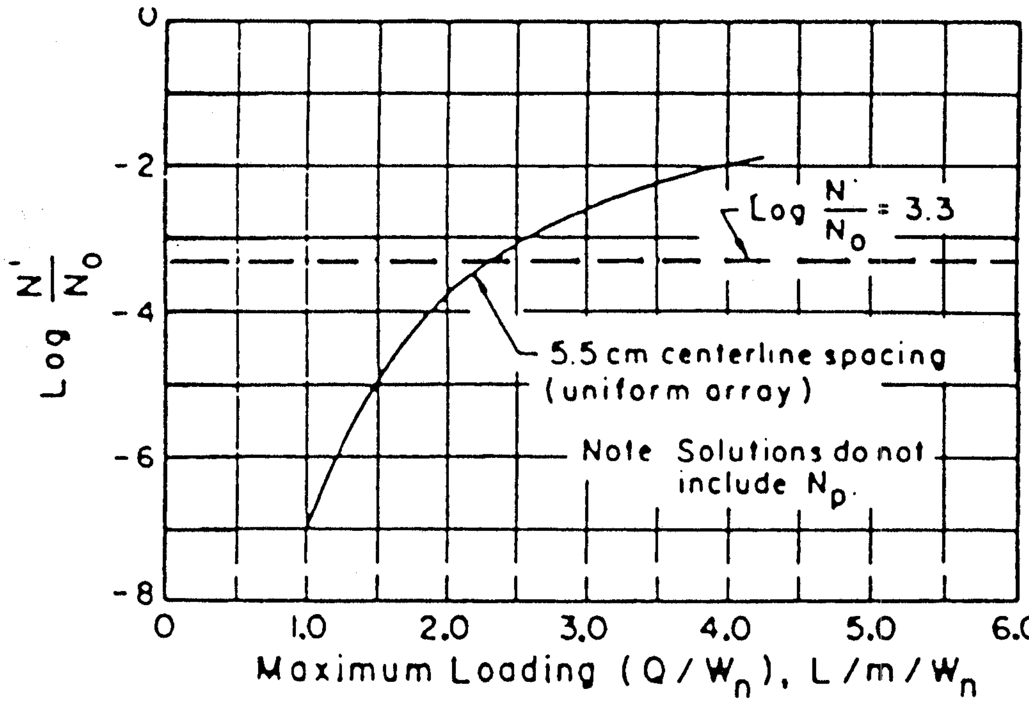

FIGURE B-1 Calculation of performance based on loading (uniform array, s = 5.5 cm)[28]

For the required effluent coliform limit, N = 200/100 ml and N_p = 92/100 ml:

$$N' = 200 - 92 = 108/100 \text{ ml}$$

Calculate Required Performance

Required performance = log (N'/N_0)

For N_0 = 200,000/100 ml (STEP 1)
and N' = 108/100 ml

then, log (N'/N_0) = log (108/200,000) = -3.3

STEP 10: SIZE REACTOR AND UV EQUIPMENT COMPONENTS

From Figure B-1, maximum Q/W_n allowed for log (N'/N_0) of -3.3 is 2.35 lpm per W_n , at the given intensity, in order to meet the 200/100 ml effluent coliform goal.

Calculate Equivalent Residence Time, t_n

$$t_n = (V_v/W_n)/(Q/W_n) \quad [12]$$

for V_v/W_n = 0.144 l/W_n (STEP 7)
and Q/W_n = 2.35 lpm/W_n (STEP 10),

then t_n = (0.144 l/W_n)/(2.35 lpm/W_n)
and t_n = 0.0613 min x 60 sec/min = 3.67 sec

Determine Number of Lamps

No. Lamps = [(Q)/(Q/W_n)]/nominal watts per lamp **[17]**

for Q = 10,000 lpm (STEP 1)
(Q/W_n) = 2.35 (STEP 10a)
watts/lamp = 26.7 (STEP 3)

then number of lamps = (10,000/2.35)/26.7 = 159

Compute Effective Length of Reactor

Effective length, $x = (1500\ t_n)^{1/2}$ (STEP 7) **[15]**

For t_n = 3.67 sec (STEP 10),

$x = [(1500)(3.67)]^{1/2}$ = 74 cm

Calculate No. of Lamps in x-direction

Lamps = $\mathbf{x/S}$ = 74 cm/5.5 cm = 13.5 since flow path is perpendicular to lamps

Summary

A total of 180 lamps is selected and placed in a 15 x 12 array. Recalculating, $\mathbf{Q/W_n}$ is now 10,000/(26.7 x 180) = 2.08 lpm, $\mathbf{t_n} = \mathbf{V_v/Q}$ = 0.144/2.08 = 4.15 sec, $\mathbf{u} = \mathbf{x/t_n}$ = (5.5 x 15)/4.15 = 19.8 cm/sec and $\mathbf{d_n} = \mathbf{E/ux}$ = 15/(19.8)(5.5)(15) = 0.0091. The example configuration is summarized in Table B-2.

Table B-2 Design sizing summary for 5.5 cm centerline spacing - uniform array

Length	15 lamps (66 cm)
Height	12 lamps (66 cm)
Total number of lamps	180
Q/W_n in lpm/W_n	2.08
Exposure time, t_n (seconds)	4.15
Velocity, (cm/sec)	19.8
Dispersion No., d_n, at E = 15 cm^2/sec	0.0092
Total power (KW)	14.4

The $\mathbf{Q/W_n}$ is now 2.08, which is below the maximum allowable of 2.35 (STEP 10). The dispersion number, **dn**, is slightly less than the objective of 0.01 (STEP 7).

Calculate Head Loss

$$\mathbf{h_L} = \mathbf{c_f}\ (\mathbf{x})\ (\mathbf{u^2}) \quad [18]$$

where $\mathbf{c_f}$ = 0.00025 sec^2/cm^2 [31]
$\mathbf{x}$ = 5.5 x 15 = 82.5 cm
$\mathbf{u}$ = 19.8 cm^2

$$\mathbf{h_L} = (0.00025)(82.5)(19.8)^2 = 8.0 \text{ cm} < 40 \text{ cm}$$
(o.k.)

The example is meant to illustrate the use of the mathematical modeling approach for a UV process design. The appropriate calibration data must first be obtained for the site specific wastewater application. The calculations are only an example and should not be used in the design of a system. Reference 27, Chapter 7 contains a more thorough computational analysis procedure and example problem.